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14. ABSTRACT

Data were collected over a 20 month period (770 tests) to identify suboptimal biomechanical, musculoskeletal, physiological, and nutritional characteristics. Based on the results of initial testing included 101st-specific task and demand analyses and biomechanical, musculoskeletal, physiological, and nutritional assessments and injury history, the Eagle Tactical Athlete Program was developed and validated. The format of ETAP was based on a sports medicine periodized training model and included specific modalities that trained the soldier to be more athletic and address the suboptimal characteristics previously identified. ETAP was validated utilizing an experimental-control group comparison design and performed during a predeployment phase of training. Soldiers performing ETAP demonstrated significant improvements of the tested variables. These adaptations occurred in variables that are critically vital to military readiness. Overall, the adaptations observed with training will have long-term implications for injury reduction and performance optimization.

15. SUBJECT TERMS
Injury prevention, performance decrement, biomechanics, musculoskeletal, physiological, nutritional

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INTRODUCTION

In 2003, the Department of Defense and the Armed Forces Epidemiological Board identified musculoskeletal injury prevention research as a necessary focus. Unintentional musculoskeletal and overuse injuries during tactical operations training, combat, and physical training are a principal health concern in the military as the US Armed Forces invest considerable resources per soldier. Soldiers of the 101st Airborne (Air Assault) have been described as tactical athletes given the functional demands of operational training and combat. Given the vigorous demands of tactical operations training, combat, and physical training, implementation of a 101st soldier-specific injury prevention and performance optimization training research initiative was warranted.

The 101st Airborne (Air Assault) Injury Prevention and Performance Optimization Program is a joint research project between the University of Pittsburgh, Departments of Sports Medicine and Nutrition and Orthopaedic Surgery, and the Division Command and Division Surgeon of the US Army 101st Airborne Division (Air Assault) at Fort Campbell. This project is funded by the United States Department of Defense and is under the auspices of US Army Medical Research and Materiel Command (USAMRMC)/Telemedicine and Advanced Technology Research Center (TATRC).

To date, this research project included performing 101st Airborne (Air Assault) soldier-specific task and demand analyses for the purposes of identifying the operational and training-related tasks during which musculoskeletal injuries occur (OCT 06-JUL 07). These data were used to create laboratory models to identify suboptimal biomechanical, musculoskeletal, physiological, and nutritional characteristics that increase the risk of training and tactical injuries while reducing the capacity for peak operating efficiency (JUL 07-AUG 08). Based on the laboratory testing results, the Eagle Tactical Athlete Program (ETAP) was developed and validated (AUG 08-MAR 09) for implementation into Division PT. The Instructor Certification Course (ICS) was developed to educate NCOs (Non-Commissioned Officers) on the theory, performance, and implementation of ETAP.

This project has provided immediate and tangible deliverables that will continue to enhance the soldiers' war time deployment preparation. Long term solutions for optimizing the training needs of the soldier will be established by providing a sustained human performance optimization approach that meets the unique demands of the tactical athlete. Improvements in the biomechanical, musculoskeletal, and physiological risk factors that are known to contribute to injury will result in a reduction of unintentional, musculoskeletal and overuse injuries and optimal physical readiness of 101st Airborne (Air Assault) soldiers. Ultimately, soldiers in the 101st Airborne will demonstrate improved safety and enhanced tactical readiness which will result in decreased time lost due to disability, personnel attrition, and the financial burden associated with medical expenses and disability compensation.

BODY

Project Overview

Phase 1 Aim 1 and Reallocated Aim 1

To identify the current prevalence of unintentional, musculoskeletal and overuse injury of Soldiers in the Army 101st during tactical operations training

Analysis of the injury data identified 77.8% of the soldiers with 0-3 unintentional musculoskeletal injuries with a distribution of upper extremity (28.8% of total injuries), lower extremity (51.0%), and neck/back (9%). Specific injuries have been reported at the foot/ankle (19% of total injuries), shoulder (13.9%), knee (11.6%), and shank (11.2%). A majority (75% of total injuries) of unintentional musculoskeletal injuries were reported during training and recreational sports

activities. Unintentional musculoskeletal injuries accounted for 60% of total injuries and overuse injuries constitute 20% of total injuries.

Phase 1 Aim 2

To perform task and demand analyses of tactical operations training in Soldiers of the Army 101st Airborne and develop protocols for Phase 2- Specific Aim 2 testing

Task analyses and demand analyses were performed for the purpose of identifying specific tactical and physical training activities during which musculoskeletal injuries occur. Task analyses have been completed for the upper extremity, lower extremity, and spine to identify injurious task performed by the 101st Airborne/Air Assault. Examination of the task analysis data directed the development of the laboratory tasks to be 101st Airborne (Air Assault)-specific for collection of biomechanical data. Based on the task analyses, laboratory biomechanical procedures were developed to simulate the daily tasks of the 101st Airborne (Air Assault) Soldiers.

Demand analyses were performed to identify the metabolic demands of the activities for comparison to physical training to determine if the appropriate energy systems are being trained sufficiently. Demand analyses also included the collection of metabolic data while Soldiers are performing simulated operations and determining the metabolic cost of wearing body armor compared to typical training and during rucksack marching (patrolling maneuvers). Analysis of metabolic data during a maximal aerobic capacity test when wearing body armor resulted in a 40% reduction in time to exhaustion, and a 20% increase in metabolic cost across similar intensities.

Phase 2 Aim 1 and Reallocated Aim 2

To prospectively determine biomechanical, musculoskeletal, and physiological characteristics which contribute to injury in Soldiers of the Army 101st

Data were collected over a 20 month period (770 tests) to identify suboptimal biomechanical, musculoskeletal, physiological, and nutritional characteristic. Several requests were made by the Command at the outset to provide immediate and tangible deliverables that will reduce the risk of injury and enhance the training capabilities of the Soldiers of the 101st Airborne (Air Assault) to assist with their deployment training. Today's Soldier, described as a tactical athlete, should possess similar physical and physiological characteristics of a well trained athlete if optimal performance is expected. For the purposes of providing immediate tangible data, the tactical athlete's physical data were benchmarked against a group of elite athletes and prescribed individual targeted training programs to address the specific suboptimal characteristics of the Soldier.

STRENGTH: Suboptimal shoulder strength was demonstrated in 20% of males and 6% of females, knee strength in 80% of males and 67% of females, ankle strength in 19% of males and 26% of females, torso strength in 37% of males and 27% of the females. Insufficient strength or imbalances of reciprocal muscle groups (shoulder/knee) may increase the risk of musculoskeletal injury due to altered joint mechanics and musculotendinous stress during functional tasks.

FLEXIBILITY: Group average flexibility was within normal limits, however significant deficits below threshold were noted in hamstring (65% males, 50% females), calf (35% males, 22% females), and hip extension (37% males, 25% females) flexibility. Insufficient flexibility will limit joint motion to perform certain functional tasks and increase the risk of musculoskeletal injuries.

BALANCE: Group average balance deficits were present for 25% of males and 35% of females with the eyes open and 20% of males and 32% of females with the eyes closed. Acute sensory information is essential to the performance of complex motor patterns, maintenance of joint stability, and preventing injury. Nighttime maneuvers require a greater reliance on somatosensory input to maintain joint stability and necessitate focused training.

PHYSIOLOGICAL: Group average body fat was high with 75% of males and 70% of females above threshold. Peak power was below threshold in 60% of males and 43% of females. Anaerobic capacity was below threshold for 75% of males and 79% of females. VO_2 max was below threshold in 80% of males and 68% of females. Lactate threshold was below threshold in 63% of males and 60% of females. A separate analysis of 159 soldiers data revealed between 52-91% are outside the normal range for the physiological variables. Excessive body fat and low aerobic and anaerobic capacity inhibits optimal physical readiness and development and increase the risk of cardiovascular disease.

BIOMECHANICS: Lower extremity biomechanics during landings were studied as this activity is associated with a high number of musculoskeletal injuries. Knee valgus was excessive in 60% of the males and 32% of females. Ground reaction forces were high in 24% of males and 20% of females. Inefficient landing mechanics and high ground reaction forces may increase the forces to the lower extremity and increase the risk of injury as adaptations are unable to dissipate the joint forces throughout the kinetic chain.

NUTRITION: Carbohydrate intake was below the recommended value for 85% of the soldiers while protein intake was below the recommended value for 69% of the soldiers. Fat intake was high in 60% of the soldiers. Total caloric intake for moderate intensity exercise was below the recommended value in 70% of the soldiers. The current macronutrient distribution is not consistent with optimizing physical performance. Adequate energy yielding carbohydrates are necessary for fueling the muscle for training, while protein is necessary for tissue recovery and regeneration.

Phase 2 Aim 2

To determine suboptimal physiological characteristics relative to demands of tactical operations training

Group average body fat was high with 75% of males and 70% of females above threshold. Peak power was below threshold in 60% of males and 43% of females. Anaerobic capacity was below threshold for 75% of males and 79% of females. VO_2 max was below threshold in 80% of males and 68% of females. Lactate threshold was below threshold in 63% of males and 60% of females. A separate analysis of 159 soldiers data revealed between 52-91% are outside the normal range for the physiological variables.

Carbohydrate intake was below the recommended value for 85% of the soldiers while protein intake was below the recommended value for 69% of the soldiers. Fat intake was high in 60% of the soldiers. Total caloric intake for moderate intensity exercise was below the recommended value in 70% of the soldiers. The current macronutrient distribution is not consistent with optimizing physical performance. Adequate energy yielding carbohydrates are necessary for fueling the muscle for training, while protein is necessary for tissue recovery and regeneration.

Phase 2 Aim 3

To develop and validate an injury prevention and performance enhancement training program

ETAP was developed from over 20 months (770 tests) of testing 101st soldiers at the Human Performance Research Center, Injury Prevention and Performance Optimization Research Laboratory at Fort Campbell. Initial testing included 101st-specific task and demand analyses and biomechanical, musculoskeletal, physiological, and nutritional assessments.

ETAP was validated utilizing an experimental-control group comparison designs. ETAP was validated during a predeployment phase of training. Soldiers included in the validation trial were currently on active duty without profile designation for either injury or failure to maintain body weight/fat standards.

ETAP validation was based on a sports medicine periodized training model and included specific modalities that trained the soldier to be more athletic. The soldier is a unique tactical athlete requiring maximal development of athletic and skill-related performance, including the interaction of aerobic endurance, anaerobic endurance, muscular strength and endurance, power, agility, and reaction ability. The periodized training program was developed to specifically address and maximize each athletic and skill-related performance component to ensure the tactical athletes are a viable force for deployment into the demands of the current conflict. Within-group stratification of exercise prescription occurred for several exercises to ensure appropriate intensity for the individual subjects. This trial was designed to induce adaptation in variables known to contribute to injury and limit performance. Given the condensed eight week schedule, physical training was restricted to the specific program activities. Soldiers performing ETAP demonstrated significant improvements (7-30%) for the sit-up and two mile run components of the Army Physical Fitness Test, and laboratory tests for knee and torso strength, flexibility, balance, and anaerobic power and capacity. These adaptations occurred in variables that are critically vital to military readiness. Overall, the adaptations observed with training will have long-term implications for injury reduction and performance optimization.

KEY RESEARCH ACCOMPLISHMENTS

- Identified suboptimal biomechanical, musculoskeletal, physiological, characteristics in the 101st soldier which are necessary for injury prevention relative to the tasks of tactical operations. Between 19-80% of the soldiers were suboptimal for any given characteristic
- Identified soldiers who met the Department of Defense % BF goals performed better on physiological and musculoskeletal tests and Army Physical Fitness Test than soldiers who exceeded the standards. The higher performance on military physical readiness tests by soldiers with a lower percent body fat substantiates the need to continue to enforce stringent body fat standards for Army personnel in order to optimize military readiness.
- Identified Division-wide physiological and musculoskeletal variance. This variance may support stratified within-unit training that accounts for the different musculoskeletal and physiological abilities, particularly if optimal performance is being sacrificed or high injury rates are observed. Stratified, within-unit training will allow for proper modification of the training stimulus that promotes optimal fitness, without inducing injury.
- Identified IBA-related changes in mechanics and ground reaction forces during a drop landing task. Proper integration of IBA into training is necessary to ensure musculoskeletal adaptation to carrying the additional loads required of tactical operations. Insufficient adaptations will likely result in undue musculotendinous stress and increase the risk of unintentional injury.
- Identified suboptimal physiological characteristics in the 101st soldier which are necessary for physical readiness relative to the demands of tactical operations. Between 43-75% of the soldiers were suboptimal for any given characteristic.
- Identified inappropriate nutritional consumption to support physical readiness and tactical training. Carbohydrate intake was lower than recommended, protein intake was lower than recommended, fat intake was higher than recommended.
- Based on the identified suboptimal characteristics, developed ETAP to result in modifications to the adaptable variables.
- Validated ETAP to induce adaptations of the modifiable biomechanical, musculoskeletal, and physiological characteristics. ETAP resulted in 7-30% improvements in the tested variables.
- Developed Eagle Tactical Athlete Program Instructor Certification School.
- ETAP in position for Division implementation under W81XWH-09-2-0095 and in preparation for Division’s next deployment cycle.

REPORTABLE OUTCOMES

Abstracts

Abt JP, Lephart SM, Sell TC, Nagai T, Rowe R, McGrail M. Kinematic adaptations with interceptor body armor in Soldiers of the Army 101st. *2008 National Athletic Trainers' Association Annual Meeting*. St. Louis, MO (June 17 - 21).

Abt JP, Sell TC, Nagai T, House AJ, Rowe R, McGrail M, Lephart SM. Field and laboratory testing variance and application to daily physical training, *2009 National Athletic Trainers' Association Annual Meeting.* San Antonio TX (June 17-20).

Chu Y, Sell T, Abt J, Huang G, Nagai T, Deluzio J, McGrail M, Rowe R, Lephart S. Knee biomechanics in Air Assault soldiers performing two-legged drop landings with and without visual input, *2009 American College of Sports Medicine Annual Meeting*. Seattle WA (May 27-30).

Abt JP, Sell TC, Nagai T, Deluzio JB, Keenan K, Rowe R, McGrail MA, Cardin S, Lephart SM. Relationship between the Army Physical Fitness Test and laboratory-based physiological and musculoskeletal assessments, *2009 American College of Sports Medicine Annual Meeting*. Seattle WA (May 27-30).

Crawford K, Abt J, Sell T, Nagai T, Deluzio J, Rowe R, McGrail M, Lephart S. Lower body fat improves physical and physiological performance in Army soldiers, *2009 American College of Sports Medicine Annual Meeting*. Seattle WA (May 27-30).

Manuscripts

Sell TC, Chu Y, Abt JP, Nagai T, Deluzio JB, McGrail M, Rowe R, Lephart SM. Additional weight of body armor alters air assault soldiers' landing biomechanics. *Mil Med.*(Provisionally Accepted)

Crawford AK, Fleishman K, Abt JP, Sell TC, Nagai T, Deluzio JB, McGrail M, Rowe R, Lephart SM. Soldiers with lower body weight demonstrate better physical and physiological performance. *Mil Med* (In preparation).

Grant Submissions

FY 08 CDMRP DRMRP ATTDA: A comprehensive health promotion and nutrition plan to prevent co-morbidities secondary to blast injuries

FY 08 CDMRP: A Comprehensive Health Promotion and Weight Management Initiative to Improve the Health, Fitness, and Quality of Life of Military Personnel

FY 09 USAMRMC/TATRC: A comprehensive weight management and performance optimization initiative to improve the health, fitness, and quality of life of military personnel

FY 10 R21 - Ancillary Studies to Large Ongoing Clinical Projects – National Institute of Arthritis and Musculoskeletal and Skin Diseases (NIH): Prevention of Ankle Injuries during Military Deployment in Afghanistan

FY 10 CDMRP - Psychological Health and Traumatic Brain Injury (PH/TBI) Research Program – Advanced Technology/Therapeutic Development Award: Exercise and Nutrition Intervention to Optimize Psychological Health for Soldiers of the Warrior Transition Unit

FY 10 Defense University Research Instrumentation Program (DURIP)- United States Army Research Office : Title: USASOC Injury Prevention and Performance Optimization Research Initiative

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Kevin Conley, PhD, ATC*	Co-Investigator	20
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Takashi Nagai, MS*	Bioengineer	100
Jennifer Deluzio*	Technician	100
Daryl Lawrence, MS*	Technician	100
John Abt, PhD, ATC*	Co-Investigator	80
Susan Casino*	Administrator	70

*On University of Pittsburgh Subcontract

CONCLUSION

Based on the results of the current aims, ETAP will be implemented into Division physical training and will be monitored to determine the effectiveness to reduce injury. Division implementation will be funded by and will be funded by W81XWH-09-2-0095. Division implementation of ETAP will involve a two-step process which includes, Instructor Certification School (ICS) and unit exposure. ICS is a four day seminar developed for NCOs to learn the theory and implementation of an updated PT program (ETAP). At the completion of the course each NCO is certified as an Eagle Tactical Athlete Training Leader. The ICS curriculum covers training program design and implementation, exercise techniques and selection, basic exercise physiology, and nutrition. The NCOs will participate in ETAP each morning and receive both lecture and practical education.

Unit level exposure will be administered by the NCOs who recently completed ICS and instruct ETAP based on the concepts learned at the school. ETAP will be extended from the validated eight week format to a monthly periodized program. The monthly program will contain the same principles by which the eight week model was developed, but will modifiy the progression of each training modality to account for the longer duration (deployment schedule-dependent). The weekly training format will be the same with individual days dedicated to a single training principle with allowances built into the program to account for combat focus training.

The certified NCOs will receive planning materials and exercise descriptions to assist in the delivery of the program. Quality control audits will be conducted by a task force comprised of the personnel from the University of Pittsburgh, G3, and Division Surgeon’s office. The quality control checks will be performed to ensure proper delivery of this training program by the NCOs to their units, answer questions related to the implementation, and assess correct performance of the exercises by the soldiers at the unit level.

A clinical trial design will be used to compare injury rates and physical readiness scores between an experimental and control group. Soldiers in the 1st Brigade Combat Team (BCT) will serve as the experimental group, while soldiers in the 3rd Brigade Combat Team will serve as the control group. The 1st and 3rd BCT were selected because of their commonality in tactical missions (considered like units) and deployment to same theater.

REFERENCES

Not applicable

APPENDICES

Appendix 1: Abstracts

Crawford AK, Abt JP, Sell TC, Nagai T, Deluzio JB, Rowe R, McGrail MA, Lephart SM. Lower body fat improves physical and physiological performance in Army soldiers. 2009 ACSM Annual Meeting, Seattle, WA (May 27-30).
The Department of the Army's maximal allowable percent body fat varies depending on gender and age, ranging between 30-36% for females and 20-26% for males. However, the Army Weight Control Program policy stipulates all soldiers are encouraged to achieve the more stringent Department of Defense goal, which is 18% body fat for males and 26% for females. PURPOSE: To determine if active duty soldiers who meet the Department of Defense percent body fat goals perform better on physiological and musculoskeletal tests and the Army Physical Fitness Test compared to soldiers who exceed the standards. METHODS: A total of 99 male 101st Airborne Division (Air Assault) soldiers (age=28±7.0 years, height= 1.77±7.4 cm, mass= 82.9±12.4 kg) participated. Percent body fat (%BF) was assessed using air-displacement plethysmography. Based on the %BF, subjects were assigned to group 1 (body fat ≤ 18%) or group 2 (body fat > 18%). Subjects completed a series of physical performance tests consisting of anaerobic power, anaerobic capacity, maximal oxygen consumption (VO2max), push-ups, sit-ups, two mile timed run test, shoulder internal and external rotation strength, and knee flexion and extension strength. RESULTS: The mean %BF was 13.3±3.7% (group 1) and 25.8±5.2% (group 2). Subjects who met the Department of Defense body fat goals (group 1) performed significantly better on seven of the 10 tests including anaerobic capacity (8.3±0.6 w/kg; 7.2±1.0 w/kg; p≤0.001), VO2max (52.2±5.4 ml/kg/min; 44.1± 6.8 ml/kg/min; p≤0.001), push-ups (78.2±18.5 reps; 65.7± 13.9 reps; p=0.002), shoulder internal rotation (66.1±16.2 N/kg; 50.4±14.5 N/kg; p≤0.001) and external rotation strength (45.4±7.7 N/kg vs. 36.6±7.4 N/kg; p≤0.001), and knee flexion (127.9±23.9 N/kg; 103.6±26.6 N/kg; p≤0.001) and extension strength (263.5±49.0 N/kg; 219.0±41.7 N/kg; p≤0.001). CONCLUSIONS: Soldiers who met the Department of Defense %BF goals performed better on the physiological and musculoskeletal tests and Army Physical Fitness Test than soldiers who exceeded the standards. The higher performance on military physical readiness tests by soldiers with a lower percent body fat substantiates the need to continue to enforce stringent body fat standards for Army personnel in order to optimize military readiness.

Abt JP, Sell TC, Nagai T, House AJ, Rowe R, McGrail MA, Lephart SM. Field and laboratory testing variance and application to daily physical training. 2009 NATA Annual Meeting, San Antonio, TX (June 17-20).
Army physical training is often performed at the unit level utilizing similar activities for each soldier regardless of differing musculoskeletal and physiological abilities. The current training format may not most effectively address unit variance to ensure the proper load application or musculoskeletal and physiological progression results. PURPOSE: To identify the between-subject variance of physical and physiological testing of the 101st Airborne (Air Assault) Division. METHODS: A total of 111 male and female 101st Airborne (Air Assault) soldiers participated (Age: 28.1 ± 6.8 years; Height: 1.74 ± 0.09 m; Mass: 79.7 ± 14.4 kg). Subjects performed the standard Army Physical Fitness Test (APFT) and a battery of laboratory assessments consisting of strength, cardiorespiratory, anaerobic, and body composition tests. Isokinetic strength testing

was performed on the shoulder, knee, and torso. VO2 max and lactate threshold were measured with a portable metabolic system during an incremental treadmill protocol to exhaustion. Anaerobic power and anaerobic capacity were measured during a 30 second maximal effort sprint on a cycle ergometer. Body composition was measured using air displacement plethysmography. The laboratory testing battery was based on variables that would most contribute to combat readiness and those most likely related to injury in the Army. A coefficient of variation (CV) was calculated for each dependent variable to determine the relative variance for APFT, musculoskeletal, and physiological testing within the Division. The dependent variables were the APFT, peak torque (normalized to body mass) for knee flexion and extension, shoulder internal and external rotation, and torso rotation, VO2 max, anaerobic power and capacity, and percent body fat. RESULTS: The CV for the APFT ranged from 13.9-28.1% for the pushup, sit-up, and run components. The CV for strength testing was 32.6% for shoulder internal rotation and 23.5% for shoulder external rotation, 24.8% for knee flexion and 21.6% for knee extension, and 24.7% for the torso. The CV for physiological testing was 37.3% for percent body fat, 18.1% for anaerobic power, 14.3% for anaerobic capacity, and 15.5% for VO2 max. CONCLUSIONS: The CV for testing ranged from approximately 14-40% indicating a large variance of scores for the APFT, musculoskeletal, and physiological testing. Such variance may support stratified within-unit training that accounts for the different musculoskeletal and physiological abilities, particularly if optimal performance is being sacrificed or high injury rates are observed. Stratified, within-unit training will allow for proper modification of the training stimulus that promotes optimal fitness, without inducing injury.

Abt JP, Lephart SM, Sell TC, Nagai T, Rowe R, McGrail MA. Kinematic adaptations with interceptor body armor in Soldiers of the Army 101st. 2008 National Athletic Trainers' Association Annual Meeting, St. Louis, MO (June 17 - 21).
Interceptor body armor (IBA) is critical to the protection of military personnel. The additional weight of the IBA may increase the musculotendinous demands and susceptibility to injury if training requirements have not specifically addressed the extra loads. PURPOSE: To compare kinematic and force changes with and without IBA during a drop landing task. It was hypothesized that wearing IBA would result in altered landing mechanics and forces. METHODS: Twenty five 101st Airborne Soldiers participated (Age: 28.2 ± 6.9 years; Height: 1.78 ± 0.07 m; Mass: 82.8 ± 11.6 kg). A 3D motion analysis and force plate system was used to capture kinematic and force data while subjects performed a single-leg, 50 cm drop landing task. The task was performed under eyes open and eyes closed conditions and with and without IBA. The IBA weighed 13.6 kg and represented the minimum additional weight required to be carried by the Soldiers. The dependent variables were knee flexion and valgus angle at initial contact, maximum knee flexion, time to maximum knee flexion, peak ground reaction forces, time to peak ground reaction forces, and average and peak slope of the ground reaction forces. RESULTS: For the eyes opened condition, maximum knee flexion increased (NIBA: 80.9 ± 16.5°; IBA: 91.0 ± 13.4°; $p < 0.001$), time to maximum knee flexion increased (NIBA: 242.3 ± 99.0 ms; IBA: 350.9 ± 217.2 ms; $p = 0.004$), peak ground reaction forces increased (NIBA: 352.2 ± 88.4 %BW; IBA: 378.6 ± 76.0 %BW; $p = 0.011$), time to peak ground reaction forces increased (NIBA: 36.3 ± 12.1 ms; IBA: 41.5 ± 8.7 ms; $p = 0.011$), and average slope of peak ground reaction forces decreased (NIBA: 36.3 ± 12.1 ms; IBA: 41.5 ± 8.7 ms; $p = 0.011$). For the eyes closed condition, maximum knee flexion increased (NIBA: 78.9 ± 15.0°; IBA: 85.5 ± 10.8°; $p = 0.001$), time to maximum knee flexion increased (NIBA: 242.0 ± 118.1 ms; IBA: 300.0 ± 80.9 ms; $p = 0.003$), and peak ground reaction forces increased (NIBA: 353.8 ± 80.3 %BW; IBA: 373.6 ± 66.2 %BW; $p = 0.039$). CONCLUSIONS: Wearing IBA during the drop landing tasks resulted in altered mechanics and ground reaction forces. Proper integration of IBA into training is necessary to ensure musculoskeletal adaptation to carrying the additional loads required of tactical operations. Insufficient adaptations will likely result in undue musculotendinous stress and increase the risk of unintentional injury.

Abt JP, Sell TC, Nagai T, Deluzio JB, Keenan K, Rowe R, McGrail MA, Cardin S, Lephart SM. Relationship between the Army Physical Fitness Test and laboratory-based

physiological and musculoskeletal assessments. 2009 ACSM Annual Meeting, Seattle WA (May 27-30).
The Army Physical Fitness Test (APFT) is administered twice a year and is designed to evaluate cardiorespiratory fitness, strength, and endurance. The APFT is scored according to gender and age for the number of completed sit-ups and push-ups per two minutes and a two mile run. Despite the goal of the testing protocol, the APFT may not provide a complete picture of individual military readiness or potential for injury. PURPOSE: To determine the relationship between the APFT and laboratory testing for physiological and musculoskeletal variables. METHODS: A total of 90 male Army 101st Airborne (Air Assault) soldiers participated (Age: 28.4 ± 7.1 years; Height: 1.77 ± 0.08 m; Mass: 83.1 ± 12.2 kg). Subjects performed the standard APFT and a battery of laboratory assessments consisting of VO2 max, anaerobic power and capacity, torso rotation strength, shoulder internal and external rotation strength, quadriceps and hamstring strength, and body composition. The laboratory testing battery was based on variables that would most contribute to optimizing overall military readiness and those most likely related to injury in the Army. Subjects were ranked according to performance for each APFT and laboratory test, with a separate cumulative ranking score calculated for the APFT and laboratory tests. A Spearman Rho correlation was calculated to determine the relationship between the cumulative ranking scores for the APFT and laboratory tests. Secondary Spearman Rho correlations were run between the APFT cumulative ranking score and the individual laboratory tests. RESULTS: A moderate relationship was identified between the cumulative APFT and laboratory testing ($\rho = 0.653$, $p < 0.001$). A moderate relationship was identified between the APFT and the VO2 max ($\rho = 0.709$, $p < 0.001$), anaerobic capacity ($\rho = 0.654$, $p < 0.001$), and body composition ($\rho = 0.632$, $p < 0.001$). CONCLUSIONS: The cumulative ranking relationship between the APFT and laboratory testing was mostly related to the VO2 max, anaerobic capacity, and body composition test. The lack of relationship between the APFT and the other laboratory tests suggests that despite the potential to score high on the APFT, additional or modified training is necessary to optimize military readiness and prevent musculoskeletal injury.

Chu Y, Sell T, Abt J, Huang G, Nagai T, Deluzio J, McGrail M, Rowe R, Lephart S. Knee biomechanics in Air Assault soldiers performing two-legged drop landings with and without visual input, *2009 American College of Sports Medicine Annual Meeting*. Seattle WA (May 27-30).
Landing tasks commonly result in non-contact knee ligament injuries and are widely performed in military training and operations. Previous civilian research has demonstrated mixed results on the effects of visual input availability on landing performance. Soldiers are frequently required to perform landings without sufficient visual input and although data are not available for fast-roping exercises performed by air assault soldiers, night time tactical maneuvers increase the risk of injury two fold. PURPOSE: To determine the differences in knee landing kinematics and vertical ground reaction forces (VGRF) of air assault soldiers with and without visual input. METHODS: A total of 110 male air assault soldiers (28.7±7.1 yrs, 177.2±7.2 cm, 83.6±12.8 kg) participated. Subjects performed a two-legged drop landing task from a 50 cm platform onto two force plates. Six high-speed infrared cameras tracked the trajectories of the reflective markers attached to subjects' lower extremities. Subjects performed three trials each with visual input and blindfolded. Knee flexion angle, knee valgus angle, and VGRFs (normalized to body weight) were compared between conditions with dependent t-tests. RESULTS: No significant differences in knee flexion and valgus angles were detected at initial foot contact. When blindfolded, maximum knee flexion was less (right: 89±20° vs. 85±20°, $p<0.001$; left: 89±19° vs. 86±20°, $p<0.001$), maximum VGRF of the left foot was greater (333.9±88.9%BW vs. 351.5±83.3%BW, $p=0.001$), and time elapsed from initial foot contact to maximum VGRF of the left foot was longer (0.374±0.10 vs. 0.394±0.09 s, $p=0.022$). CONCLUSION: Diminished visual acuity caused the subjects to alter their landing strategy for the two-legged drop landing task. While the greater VGRF of the left foot may pose greater risk of injury, soldiers are able to dissipate the force by prolonging the time from initial foot contact to peak VGRF. Significant differences found only with the left leg raises the question whether landing strategies change based on the availability of visual input, perhaps increasing asymmetrical or preferable joint loads.

Appendix 2: Manuscripts

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Minimal additional weight of combat equipment alters air assault soldiers' landing biomechanics

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KEYWORDS
Drop Landing, Non-contact Knee Injury, Weight Carrying, Injury Prevention

Abstract
The additional weight of combat and protective equipment carried by soldiers in battlefield and insufficient adaptations to this weight may increase the risk of musculoskeletal injury. The objective of this study was to determine the effects of the additional weight of equipment on knee kinematics and vertical ground reaction forces (VGRF) during two-legged drop landings. We tested kinematics and VGRF of 70 Air Assault soldiers performing drop landings with and without wearing the equipment. Maximum knee flexion angles, maximum vertical ground reaction forces, and the time from initial contact to these maximum values all increased with the additional weight of equipment. Proper landing technique, additional weight (perhaps in the form of combat and protective equipment) and eccentric strengthening of the hips and knees should be integrated into soldiers' training to induce musculoskeletal and biomechanical adaptations in order to reduce the risk of musculoskeletal injury during two-legged drop landing maneuvers.

Introduction

Musculoskeletal injury is a persistent and major health concern for individuals who are responsible for the medical care of military personnel. According to the Armed Forces Epidemiological Board (AFEB), injuries “impose a greater ongoing negative impact on the health and the readiness of U.S. Armed Forces than any other category of medical complaint during peacetime and combat.”[1] More casualties have been caused among U.S. troops by non-combat injuries and disease than by combat.[2] Data presented to the AFEB’s Injury Control Work Group by scientists from Navy and Army research organizations, and published military and civilian epidemiologic studies has revealed that the most common types of injuries seen in military populations are unintentional musculoskeletal overuse injuries.[3] A review of the medical treatment records in a group of 298 male infantry soldiers showed that musculoskeletal injuries were very common; musculoskeletal pain was the most common diagnosis followed by strains. Also, a higher cumulative incidence of soldiers with musculoskeletal injuries was associated with reduced physical fitness (2-mile run and sit-ups).[4] A study of data in an Army database of all hospital admissions (due to an external cause of injury) for active duty personnel showed that during a 6-year time period, 11% (13,861) of the patients had injuries sustained during sports or physical training. Of these, musculoskeletal injuries were very common (fractures - 33%, sprains/strains - 29%, and dislocations - 15%). Sports and Army physical training injuries accounted for a significant amount of lost duty time.[5] An analysis of the Navy Physical Evaluation Board data showed that the most common diagnostic categories of cases were musculoskeletal disorders (43 %), and injuries and poisonings (15 %).[6] Recently, a survey by Sanders et al[7] among military personnel involved in Operation Iraqi Freedom and Enduring Freedom revealed that 34.7% of soldiers reported non-combat injuries.

Musculoskeletal conditions and injuries are the leading causes of hospitalization in the U.S. Army, accounting for 31% of all hospitalizations in 1992.[8] Orthopaedic and musculoskeletal issues accounted for 53% of all U.S. Army injury cases that were reviewed by the disability evaluation process of the Physical Evaluation Board in 1994.[9] Similarly, 58% of such cases in 2005 in the U.S. Navy were due to musculoskeletal conditions and injuries.[6] The high rate of overuse injuries adversely affects military training, resulting in lost days and increased medical costs.[10] The annual cost of injury-related disability in the military had exceeded $750 million in mid-1990s,[1, 9] and the annual expenditure of the U.S. Department of Defense to treat musculoskeletal injuries had been $600 - 750 million prior to 2001.[11] Such injuries will have long term consequences even after individuals have left active duty. For example, among the veterans returning from Iraq and Afghanistan who have sought Veterans Administration health care between 2002 – 2006, 42% were due to musculoskeletal issues such as joint and back disorders.[12]

The knee is one of the most common sites of musculoskeletal injury in the military, accounting for 10 - 34% of all injuries among different military groups from Army Infantry to Naval Special Warfare trainees.[3] The mechanism responsible for knee injuries in the military has not been clearly outlined, but they are hypothesized to be similar to the mechanism responsible for knee injuries in athletes. Most traumatic non-contact knee injuries occur during demanding athletic tasks that include sudden deceleration, landing, and pivoting maneuvers,[13] which are all prevalent in military training, tactical operations, and sports activities. Among these tasks, landing from a raised platform may be one of the most critical and the most common. Landing is involved widely in infantry soldiers’ training and operations, such as jumping off the back of a vehicle, traversing a ditch, and landing after a climb over a wall or other obstacle. These landings typically induce dangerously high ground reaction forces, which will be transferred through the knees. Biomechanical and epidemiological research has linked several dangerous kinematic and kinetic characteristics during landing to a greater risk of non-contact anterior cruciate ligament (ACL) and secondary injuries in athletes.[14, 15] Our own research has demonstrated that groups at-risk for knee injury perform landing and cutting maneuvers with dangerous landing positions, which includes greater ground reaction forces, altered electromyographic activity, and increased joint loading.[16-19] Due to similar injury mechanisms in the military, the same models employed to study biomechanics in athletes are appropriate for use in military populations.

Although soldiers perform very different tasks than typical athletes, soldiers must be able to perform and react similarly and can be considered tactical athletes. While athletes can sometimes modify equipment (lighter shoulder pads in football for instance), soldiers do not have the convenience of improving their agility in the field by using lighter equipment. Instead, soldiers must wear the required heavy and uniformed protective equipment and must also carry weapons, ammunitions, communication devices, and other equipment for combat. The weight a soldier carries while marching has increased throughout the past century.[20] Such additional weight can alter soldiers' normal body movement patterns, increase joint stress, and potentially increase their risk of suffering musculoskeletal injuries. For example, Army officials have reported that the 60 – 70 kilograms of weight (approximately 65% to 75% of the soldier's body weight (BW)) that U.S. soldiers routinely carry in the mountains of Afghanistan has increased the number of soldiers who have been categorized as "non-deployable" due to musculoskeletal injuries.[21] Previous research studies demonstrated that carrying a military rucksack (approximately 15% - 30% of the soldier's BW) can initiate compensatory kinetic response at the knees,[22] elevate the forces applied on the upper and lower back,[23] and increase the thoracic and lumbar spine curvature.[24] The additional weight may also alter landing kinematics and ground reaction forces. Kulas et al.[25] studied the effect of a vest of 10% BW on recreationally active civilian participants performing two-legged drop landing from a 45 cm height platform. They reported increased angular impulse and energy absorption but no significant change in maximum knee flexion angles, while ground reaction forces and knee valgus angles were not mentioned.[25]

The biomechanical response to additional weight has not been extensively studied in a military population. Therefore, the main purpose of this study was to investigate the effects of additional weight on soldiers' kinematics and kinetics, and their potential implication on lower extremity musculoskeletal injury using similar biomechanical models we have previously employed in athletes.[16-19] Although the effects of additional weight should be observed throughout the lower extremity, we chose the knee joint as the main focus of this study. We used standard military body armor, a helmet, and a rifle to represent the minimal additional weight a soldier would carry in a combat setting. As a part of our ongoing 101st Airborne (Air Assault) Injury Prevention and Performance Optimization Program, soldiers from the 101st Airborne Division (Air Assault) participated in this study. We hypothesized that wearing body armor, a helmet, and carrying a rifle would result in greater knee flexion and knee valgus angles at initial foot contact, greater maximum knee flexion angle, prolonged time from initial foot contact to maximum knee flexion, greater maximum vertical ground reaction forces (VGRF), and a prolonged time from initial foot contact to maximum VGRF, compared to without wearing the additional weight. This study is among a limited number of investigations examining the effect of additional weight on biomechanics of drop landing, and is the only one recruiting participants strictly from a military population. We expect the results of this study will provide evidence-based insight to modify soldiers' training, accounting for the necessary loads carried during combat, in order to reduce the risk of injury.

Methods

Participants

Seventy 101st Airborne (Air Assault) soldiers volunteered to participate in this study (Age: 28.8 ± 7.1 yrs; Height: 1.78 ± 0.07m; Mass: 84.1 ± 12.8kg). To be included, potential participants must have been have been from the 101st; must have been male; 18 – 45 year-old; no history of concussion or mild head injury in the previous year; no upper extremity, lower extremity, or back musculoskeletal pathology in the past three months that could affect the ability to perform the tests within this; and no history of neurological or balance disorders. All participants were cleared for active duty without any recent prescribed duty restrictions. Participants provided informed consent prior to participation. The current study was approved by the university's institutional review board (0506094), Eisenhower Army Medical Center (DDEAMC 07-16), Army Clinical Investigation Regulatory Office, and Army Human Research Protection Office (HRPO # A-14020). All tests were conducted at our Human Performance Research Laboratory, Fort Campbell, KY, a

remote research facility operated by the Neuromuscular Research Laboratory, University of Pittsburgh.

Instrumentation

Six high-speed cameras (Vicon, Centennial, CO) operating at 200Hz were used to capture the participants' kinematic data. Vertical ground reaction forces were measured using two Kistler force plates (Kistler Corporation, Amherst, NY) at a frequency of 1200Hz. The soldiers used their own personalized Interceptor Body Armor (IBA) (Point Blank Body Armor, Inc., Pompano Beach, FL) and Advanced Combat Helmets (Gentex Corp., Simpson, PA) for the test. An assault rifle replica (M4 Carbine model) was provided by the researchers. The total weight of the interceptor body armor, helmet, and rifle replica was 15.0 ± 3.7kg, or 18.0 ± 4.3% compared to each participant's BW. The authors recognize the actual weight carried by the soldiers will vary considerably depending on their work demands and could not control for potential differences between soldiers. The weight of the IBA, helmet, and rifle, however, represented the minimal additional weight required to be carried by the soldiers as part of tactical operations excluding the combat uniform and boots not worn as part of this study.

Procedures

Sixteen reflective markers were placed bilaterally on the participants' anterior superior iliac spines (ASIS), posterior superior iliac spines (PSIS), lateral thigh, lateral femoral epicondyle, lateral shank, lateral malleoli, posterior calcanei, and 2nd metatarsal head (dorsal surface), according to Vicon's Plug-in Gait model (Vicon, Centennial, CO). The lateral thigh markers (mid-femur) were placed in line between participants' greater trochanter (as palpated) and the lateral femoral epicondyle marker, and the lateral shank markers were placed in line between the lateral femoral epicondyle marker and lateral malleolus markers. A static trial was captured for each participant in the anatomical position and served as the baseline for joint angle calculations. The participants were asked to perform two-legged drop landings from a platform of 50 cm height under two conditions: with and without wearing the IBA, helmet, and rifle; henceforth referred to as the IBA condition (Figure 1) and non-IBA condition (Figure 2) respectively. Participants were instructed to stand near the edge of the platform, and drop off when the researchers gave the command. The participants were to land on both feet on the two force plates, and remain standing for two seconds after regaining their balance. The task was described and demonstrated by the researcher. For each condition, the participants were given at least three practice trials. All trials for both conditions were performed on the same day with approximately 30 to 60 seconds in between trials within each condition and approximately five minutes between the two conditions. Trials during which the participants did not drop off the platform properly, failed to regain balance, touched the ground off the force plates, or did not land on the force plates were rejected.

Data Reduction

The 3D coordinates of the video-captured reflective markers were reconstructed and synchronized with the vertical ground reaction force (VGRF) data using Vicon Nexus software (Vicon Motion Systems, Inc., Centennial, CO). We used a general cross validation Woltring filter to smooth the reconstructed 3D coordinates.[26] The Vicon Plug-in gait model uses ASIS and PSIS markers to estimate the position of hip joint centers. However, in order to account for coverage of the ASIS markers by the IBA, we placed these markers on the IBA itself. Unfortunately, this invalidated the 3D joint angle calculations as they no longer reflected the anatomical landmarks on which they were intended. Therefore we decided to use 2D angles defined only by those markers on the legs, which were not affected by the ASIS markers.

The filtered 'x', 'y', and 'z' coordinates and force plate data were processed with a custom Matlab (The Mathworks, Natick, MA) program to calculate joint angles and identify critical events. The knee flexion angle was defined as 180° minus the inner angle formed by lateral thigh, lateral knee, and lateral malleolus projected on the sagittal plane. The knee valgus angle was defined

as 180° minus the inner angle formed by the three markers projected on the frontal plane. The joint angles during the dynamic tasks were corrected by the baseline angles from the static trial. Initial contact was defined as point at which the vertical ground reaction forces exceeded 5% of the participant's body mass. Variables assessed in the current study included knee flexion and knee valgus at initial foot contact, maximum knee flexion, time to maximum knee flexion, maximum VGRF, and time to maximum VGRF. Three trials for each participant were averaged for statistical comparisons.

Statistical Analysis

Dependent t-tests were used to examine the differences of selected variables with (IBA) and without (Non-IBA) wearing IBA. Each participant would serve as his own control. Statistical analyses were performed using SPSS software (SPSS Inc., Chicago, IL). The alpha level was set at < 0.05.

Results

The results are presented in Table 1. The participants demonstrated no statistical difference between the IBA and non-IBA conditions for knee flexion or knee valgus angles at initial contact. Under the IBA condition, the participants had significantly greater maximum knee flexion and greater maximum VGRF; the time from initial contact to these peak values were also significantly longer.

Discussion

Equipment for personal protection and combat purposes places additional weight on the soldiers' bodies, which might alter their kinematics and kinetics, and therefore increase the risk of musculoskeletal injuries. The purpose of this study was to investigate the biomechanical effects of additional weight on air assault soldiers performing landing tasks, and the potential implication of the alterations on lower extremity musculoskeletal injuries, using the biomechanics model we previously developed.[16-19] This study focused specifically on the VGRF and knee kinematics during landing, which is a task that Air Assault soldiers frequently perform during combat activities such as jumping out of a helicopter or a truck, and traversing uneven terrain or obstacles. Based on the 70 soldiers tested, we found greater maximum knee flexion, greater maximum VGRF, and prolonged time from initial contact to these two peak values with additional weight. We believe that specific strength training, proper landing skills, and properly increased exposure to weight carrying during physical training should be addressed to induce musculoskeletal adaptations that will likely reduce the risk of knee injuries in Air Assault soldiers.

The effects of additional weight carried by soldiers on knee kinematics and VGRF have several implications on training and injury prevention. First, the additional weight requires considerable lower extremity strength to land safely especially at the knee as the quadriceps must eccentrically contract to absorb and dissipate landing forces. Momentum is the product of the mass and the velocity of an object. Therefore, the kinetic influence of additional weight on soldiers' bodies and potentially landing kinematics is similar to landing without additional weight from a greater height or, equivalently, with additional weight at greater velocity. Maximum knee flexion angles,[27] as well as the range of knee flexion,[27, 28] increases with drop landings from a raised platform height. A simulated parachute landing study demonstrated greater maximum knee flexion, greater range of knee flexion, and longer time to maximum knee flexion when participants dropped from a higher position.[29] During knee flexion, the knee extensors eccentrically contract to decelerate the body, and dissipate the impact, and absorb the energy transferred-up from the ground.[28, 30] As expected, our participants demonstrated increased maximum knee flexion and a longer time to reach maximum flexion with IBA; it naturally takes more knee angular displacement and time to stop the downward movement of the body with increased momentum. When such demand increases, a greater portion of the energy absorption shifts to the knee and hip extensors from the ankle muscles,[28, 30, 31] which have limited energy-dissipation capacity. The eccentric strength of knee extensors are considered a potential factor affecting maximum knee flexion during landing.[16]

Although our participants demonstrated an appropriate adaptation of flexing the knees more, the additional weight added in the current study was only minimal and may not be reflective of actual carrying loads. As carry loads increase during tactical operations, the demand on muscular strength, especially eccentric strength at the knees and hips, would increase significantly in order to perform safe landings.

Second, proper landing techniques should be emphasized to address the increased VGRF and accompanied risk of injury. The vertical ground reaction force induces an external knee flexion torque. To counterbalance and control the knee flexion torque, there exists an internal knee extension torque (quadriceps activation), which simultaneously increases the ACL strain by producing an anterior shear force on the proximal tibia.[32] Our previous research has demonstrated that the greater the internal knee extension torque, the greater the proximal tibia anterior shear force.[19] Activation of the quadriceps which increases anterior shear force by way of the patella tendon[32] is also pre-activated before initial contact.[29, 33-35] Depending on the knee alignment at the instant of landing, the VGRF may increase the knee valgus torque, which can further increase ACL strain in the presence of anterior shear force at the knee.[36, 37] Valgus alignment of the knee at landing has been considered a risk factor for non-contact ACL injury.[15] In addition to landing with greater knee valgus, those individuals at greater risk for injury experience greater proximal tibia anterior shear force during landing even when their vertical and posterior ground reaction forces are not significantly higher than those at less risk for noncontact ACL injury.[18] While our participants did not show any sign of more dangerous knee alignment in the frontal plane with additional weight, the increased maximum VGRF they experienced has been linked to increased risk of non-contact ACL injuries.[15]

In the current study, an average of 18% of additional weight increased the maximum VGRF by 35% BW on each leg (based on data derived from Table 1); with the additional weight of weapons, ammo, and other combat equipment, the maximum VGRF during landing is expected to increase dramatically in tactical operations. In a previous study, the vertical ground reaction forces increased from 256% BW to 474% BW as the height of the dropping platform rose from 32 cm to 103 cm (equivalent to an increased velocity from 2.5 m/s to 4.5 m/s).[28] Our 50 cm platform, equivalent to a 3.1 m/s velocity, yielded a comparable 355% BW maximum VGRF under the non-IBA condition and 391% BW under the IBA condition. A High Mobility Multipurpose Wheeled Vehicle (HMMWV), widely used by the U.S. Army, has a deck height of approximately 84 cm, and the height of a window or a wall and the depth of a ditch can be close to a meter or more. Moreover, the maximum VGRF experienced during landing tasks performed in the field could be much greater than the standardized drop landing task performed indoor. A simulated parachute landing yielded 930% BW (9.3 times body weight) and 1,310% BW (13.1 times body weight) of maximum VGRF at vertical velocities of 3.3 and 4.5 m/s, respectively.[29] Such high VGRF was very close to the greatest value ever documented, in a single-leg double back somersault landing (1,440% BW).[38] The exact reason for such a large increase in maximum VGRF between tasks is difficult to determine; however, performing such a task is more dynamic, and has much higher uncertainty and unpredictability than a well-controlled standardized task. During tactical operations soldiers will quickly react to the environment and operation conditions and may not have time to prepare for the landing. In such context soldiers may not be able to use their full capacity to reduce the impact. Thus, we would expect an even higher maximum VGRF that the Air Assault soldiers would encounter frequently in the battlefield.

One technique to reduce the VGRF is to increase the knee flexion angle at initial contact, and allow greater knee flexion throughout the landing.[28, 30] Females, who are more vulnerable to non-contact knee injuries, demonstrate lower knee flexion angles at initial contact during two-legged landing,[14, 27] although a limited amount of research has shown no gender differences[39] or increased knee flexion in females[34] also exists. With less knee flexion, less energy can be absorbed, and more energy is transferred to the knees and hips from the ankles. We hypothesized that the knee flexion angles at initial contact would be greater under the IBA condition, assuming the additional weight would lead to a more cautious move. However, our participants demonstrated no statistical difference between conditions. We do not have sufficient

information to conclude whether or not soldiers would land with a more extended knee when additional weight is carried based on the current study and research design. Although the effect of additional weight was similar to increased dropping velocity in many ways, we also do not have a clear answer as to how a greater velocity would affect the knee flexion angle at initial contact. Huston et al.[27] found that knee flexion angle increased with increasing velocity during two-legged drop landings. In contrast, a more extended knee with greater velocity was observed in simulated parachute landing, which may explain the concurrent high maximum VGRF observed.[29] While the task Huston et al.[27] used was more comparable to ours, the results from the simulated parachute landing may be more valuable to our research purposes. We cannot rule out the possibility that soldiers would land with more extended knees performing tactical operations in field with additional weight.

In this study, we demonstrated the effect of additional weight on knee kinematics and VGRF of soldiers performing a two-legged drop landing task. These effects may increase the risk of lower extremity musculoskeletal injuries during a similar landing task, however, landing is not the only task that the additional weight could affect, and the knee is not the only joint subjected to increased risk of injury under the increased stress due to the additional weight. Military load carriage can also increase the ground reaction forces during walking,[40] alter pelvic and hip angles during standing,[41] and decrease balance and postural stability.[42] Craniovertebral angle and femur range of motion,[43] thoracic and lumbar spinal curvature,[24] forces suffered at the upper and lower back,[23] and trunk muscle activation patterns[41] can all be adversely affected by additional weight. Alterations in physiological performance, such as increased oxygen consumption, heart rate, ventilation, perceived exertion, and decreased knee muscles extension torque output were all evident in a simulated marching test with increased carried weight, suggesting the fatiguing effects of the heightened demands of additional load.[22, 44] Our preliminary data from another study has also demonstrated similar effects with additional load (body armor and helmet = 18.6 kg). The addition of the body armor and helmet increased the peak VGRF during gait by 18.7% BW and the time to exhaustion during a VO2 max test decreased by 50% and caloric expenditure increased by 20%. Considering the trend of increasing weight carried by soldiers throughout history,[20] the effects of this weight on soldiers' performance and safety in tactical operations is an ongoing concern for soldiers effectiveness and safety.

Since additional weight considerably increases the mechanical and physiological demands and potentially contributes to musculoskeletal injuries, integrating additional weight into soldiers' regular physical training seems prudent. Soldiers build their strength through their daily Army physical training, and sharpen their combat skills through regular tactical training. However, soldiers frequently wear only fitness clothing and running shoes during physical training. Additional weight may be worn during tactical training, yet a progressive program to induce adaptations has not been implemented. On the other hand, during their deployment, soldiers are equipped with additional weight sometimes significantly more than encountered in previous physical and tactical training. The inconsistent exposure to additional weight during training may not induce the musculoskeletal demands to allow soldiers to build and maintain sufficient strength and develop adequate kinematic adaptations to meet the combat mission tasks. Increased integration of additional weight into physical training that simulates the demand of their tactical operations is therefore encouraged, as it may reduce the risk of injuries and promote soldiers' combat readiness.

We acknowledge this study has several limitations. First, we had to use 2D projection angles instead of 3D joint angles due to marker placement issues. Knee flexion and knee valgus angles can affect each other when the values are large. However, we only assessed knee valgus angle at initial contact, while knee flexion angles were small. And the knee valgus angle was low throughout the landing task and would have limited effect on the knee flexion angles. Second, the order the two testing conditions were not randomized. A learning effect could have influenced the measurements during the IBA condition because it always followed the non-IBA condition. In an attempt to address this issue, we provided at least three practice trials for each condition and allowed more practice until participants felt comfortable and prepared. We believe participants

could familiarize themselves with the landing tasks through practice, and therefore the order of the two testing conditions would not provide further alteration of performance. We also felt this order of testing was a safer protocol. Third, the current study did not include ankle kinematic calculations. Lephart et al.[16] suspected that ankle kinematics may affect the VGRF of landing tasks. Future studies investigating how the ankles would respond with increasing mechanical demands could provide additional insight of military injury prevention, particularly given the rate of ankle injury.

Conclusion

Even the minimum additional weight soldiers carry such as the addition of body armor, helmet, and a rifle, causes altered kinematics and ground reaction forces. These alterations attributed to carrying additional weight may increase the risk of knee and other lower body injuries. Gradually integrating additional weight, such as body armor, into the soldiers' physical training is recommended to promote kinematic adaptations and safer performance during landing tasks.

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Table 1

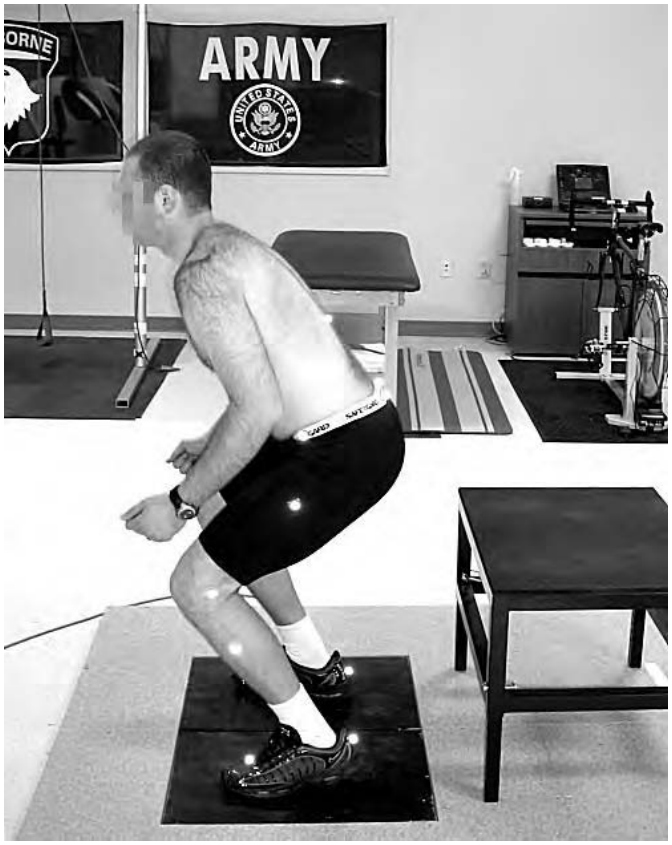
TABLE 1
Comparisons of knee joint angles, vertical ground reaction forces, and timings between Non-IBA and IBA conditions

	Right Leg			Left Leg		
	Condition		p-value	Condition		p-value
	Non-IBA	IBA		Non-IBA	IBA	
Knee Flexion Angle at Initial Contact (degrees)	10.5 ± 5.6	10.4 ± 5.5	0.905	12.5 ± 6.2	11.8 ± 6.5	0.107
Knee Valgus/Varus Angle at Initial Contact (degrees) (Positive=Valgus, Negative=Varus)	0.0 ± 10.1	-1.0 ± 11.8	0.466	-2.9 ± 13.8	-3.7 ± 14.8	0.566
Maximum Knee Flexion Angle (degrees)	76.2 ± 17.6	82.2 ± 14.4	<0.001	77.6 ± 18.8	84.4 ± 16.4	<0.001
Time to Maximum Knee Flexion Angle (milliseconds)	239 ± 88	298 ± 73	<0.001	240 ± 102	292 ± 76	<0.001
Maximum Vertical Ground Reaction Force (Percent Body Weight)	371.2 ± 100.7	398.1 ± 94.3	0.002	330.5 ± 96.7	374.6 ± 88.2	<0.001
Time to Maximum Vertical Ground Reaction Force (milliseconds)	37 ± 11	42 ± 9	<0.001	36 ± 12	40 ± 10	0.004

Statistical Significance set at $p < 0.05$

Figure 1. Two-legged drop landing task, IBA condition

Figure 2. Two-legged drop landing task, non-IBA condition



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Lower Body Fat Improves Physical and Physiological Performance in Army Soldiers

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Abstract

The Army Weight Control Program encourages soldiers to achieve the body composition standard of the Department of Defense (DoD), which is 18% body fat for males. The purpose of this study was to compare physical and physiological fitness test performance between soldiers meeting the DoD standard and those exceeding the standard. Ninety-nine male 101st Airborne (Air Assault) soldiers participated. Subjects completed the Army Physical Fitness Test and tests for body composition, anaerobic power, maximal oxygen consumption, and isokinetic strength. Subjects were assigned to groups based on the DoD's standard for body fat (Group 1: ≤18% BF; Group 2 >18% BF). Soldiers who met the DoD's standard performed significantly better on seven of ten tests. Higher physical and physiological fitness test performance by soldiers with lower body fat confirms the need to enforce body fat standards for Army personnel in order to optimize physical readiness.

Introduction

The Army Weight Control Program (AWCP) was originally established in response to the need to improve overall fitness in the United States Army.[1] The AWCP (AR 600-9) 1984 guidelines stipulated that excessive body fat "connotes a lack of personal discipline, detracts from military appearance, and may indicate a poor state of health, physical fitness, or stamina.[1]" The Department of Defense (DoD) and Army enforce age and gender-specific body composition standards at which they recommend personnel to achieve. Men are recommended to maintain a range of 20-26% (Army standard) body fat with an optimal goal of 18% (DoD standard), and women are recommended to maintain a range of 30-36% (Army standard) with an optimal goal of 26% (DoD standard). In 2007, 13,364 soldiers exceeded the upper limit of these standards and were enrolled in the AWCP to reduce overall body weight and fat. [2] Since 1992, approximately 24,000 soldiers have been discharged due to failure to maintain appropriate age and gender-specific weight and fat composition and comply with the AR 600-9. [3] Despite multiple efforts to provide a comprehensive weight control strategy in military personnel,[4, 5] a recent report from the Armed Forces Health Surveillance Center revealed a drastic increase in the number of active component Military service members diagnosed as overweight, with numbers increasing from approximately 25,000 to 70,000 over the last decade.[6] Specifically, in 2005, 61% of men and 39% of women had a BMI above 25 kg/m^2, and 12% of all active service members had a BMI of over 30 kg/m^2.[6] This alarming statistic causes concern about the detrimental effects of carrying excess body fat on physical and physiological test performance as well as overall physical health and injury risk.

Increased body fat may result in decreased physical readiness, elevated risk for musculoskeletal injury, and increased cardiovascular risk.[7-12] In previous research, body composition has proven to have a significant impact on physical performance. Specifically, studies have shown that active individuals who have a higher percent of their total weight as fat may be less physically fit than their leaner counterparts.[7, 9, 10] Knapik et al[9] reported an upward trend for body fat and fat-free mass of male military recruits from 1978 to 1998, and coincidentally, a decline in performance was observed during this time period. Specifically, in this review of literature, researchers found by linear regression that 2-mile run times for men were 10% slower in 2003 than in 1987, and women ran 6% slower in 2003 than 1988.[13-21] Researchers hypothesized that decreased fitness may have been due to the recruits not fully achieving their aerobic capacity potential in performance tasks, such as timed runs, possibly because of increased bodyweight, reduced experience with running, lower motivation, and/or environmental factors.[9] In a prospective cohort study of 140 healthy male military conscripts, increased fat mass and fat percent were strong predictors of poorer physical fitness as evidenced by 12-minute running performance, with a 1% increase in fat shortening the 12-minute running distance by 19.3 meters.[10]

In a study that examined risk factors for ACL injury of males and females in a class of Army Cadets, increased body mass index (BMI) presented a 2.0 relative risk factor for non-contact ACL injury. The relative risk elevated significantly when BMI was analyzed in conjunction with additional risk factors, such as femoral notch width, generalized joint laxity, and KT-2000 test results.[12] Also, in a retrospective longitudinal analysis of fat distribution and cause-specific mortality in the army, waist-to-hip ratio and BMI were predictive of risk of premature ischemic heart disease mortality in an initially relatively healthy population of young men.[11]

To date, research has demonstrated that excess body weight carried as body fat can decrease physical performance, specifically locomotor tasks involving carrying one's own body weight. Additionally, surplus body fat may also impose a greater risk for injury, lost duty, and thus create a financial burden to the Department of Defense. The purpose of this study was to compare performance on physical and physiological fitness tests between soldiers meeting the DoD standard and those exceeding the standard. It was hypothesized that male soldiers who met the optimal body fat goal of 18% or less would perform better on physical and physiological fitness tests and the Army Physical Fitness Test in comparison to those soldiers who are above this level. By analyzing the outcomes of a variety of laboratory and field physiological and musculoskeletal tests, this study may potentially identify further performance inhibiting characteristics and injury risk factors in the population not achieving the DoD body fat standard.

Methods

Subjects

Subjects were recruited from the Army 101st Airborne (Air Assault). A total of 99 male soldiers (age: 28.0 ± 7.0 years, height: 177 ± 7.4 cm, mass: 82.9 ± 12.4 kg) participated. The study obtained approval from the University of Pittsburgh's Institutional Review Board, Eisenhower Army Medical Center, Clinical Investigation Regulatory Office, and Human Research Protection Office as part of an ongoing research project focusing on Optimization of Performance and Injury Prevention in the Department of Defense.

Dependent Variables

Body composition, measured as percent body fat (BF%), was the main outcome variable to categorize subjects into groups based upon Army recommendations [1] (Group 1: BF ≤ 18%, Group 2: BF > 18%). Physiological variables included anaerobic power (W/kg); anaerobic capacity (W/kg); maximal oxygen consumption (ml/kg/min); the Army Physical Fitness Test consisting of push-ups and sit-ups performed in two minutes, and a two-mile timed run; peak isokinetic knee flexion and extension (%BW); and peak isokinetic shoulder internal and external rotation (%BW). Laboratory testing was performed in the Human Performance Research Center at Ft. Campbell by the same research associates on two separate days, with at least 24 hours separating each test day. Body fat, isokinetic knee strength, and isokinetic shoulder strength, and anaerobic peak and capacity were tested on Day 1 and maximal oxygen consumption was performed on Day 2. The components of the APFT were performed on a separate occasion in a field setting.

Body Composition

The Bod Pod® Body Composition System (Life Measurement Instruments, Concord, CA; see Figure 1) was used to measure percent body fat. The Bod Pod utilizes air-displacement plethysmography to measure body volume and calculate body density. The subject wore minimal clothing consisting of spandex shorts and a spandex swim cap to eliminate excess air entrapment. The subject sat inside the device until two body volumes were measured within 150ml. Body fat percent was calculated using predicted lung volume and an appropriate densitometry equation.[22] Intrasubject reliability within our laboratory has demonstrated an intraclass correlation coefficient (ICC) of 0.98 and standard error of measurement of 0.47% body fat. Based on the percent body fat, subjects were assigned to the respective groups (Group 1: body fat ≤18%, Group 2: body fat > 18%). These groups were established to compare the results of the following physiological fitness tests.

Anaerobic Power

Anaerobic power was measured using a VeloTron® cycling ergometer (RacerMate, Inc, Seattle WA; see Figure 2). Subjects performed a 30-second Wingate protocol in order to measure anaerobic power and anaerobic capacity.[23] The subject sat on the ergometer and proper seat and handlebar adjustments were made. The subject's feet were secured to the pedals and a warm-up cycle at a self-selected cadence was initiated. The subjects performed a maximal intensity 30 seconds pedaling output. The researcher provided standard verbal instructional cues during the test to alert them to pedal against the resistance of the cycle. Anaerobic capacity was reported as the relative average watts produced during the 30 seconds of the test. Anaerobic power was reported as the relative peak watts produced during the first five seconds of the test.

Maximal Oxygen Uptake

A portable metabolic system (Viasys, San Francisco, CA; see Figure 3) was used to assess oxygen consumption during a maximal oxygen consumption treadmill test. This instrument was calibrated with known gas mixtures and measured values corrected to standard temperature, pressure, and density. The metabolic system, consisting of a small 48.0 cm^3 rectangular apparatus and battery, was attached to the front of the subject. A heart rate monitor (Polar USA, Lake Success, NY) was worn by the subject around the chest at the level of the zyphoid process. The subject's performed a brief warm-up at a self-selected speed on the

treadmill prior to testing. A modified protocol [24] was used, with subjects running at a constant speed and with a 2.5% increase in grade at the end of each 3-minute stage. The subjects' speed was determined as 70% of the mile pace from their 2 mile-run time during the APFT. Subject termination was determined by volitional fatigue.

Army Physical Fitness Testing

On a separate occasion, subjects completed the APFT including a push-up test, a sit-up test, and a two-mile timed run. The push-up and sit-up tests were performed according to the Army standard protocol,[2] which is the maximal number push-ups or sit-ups the subject was able to complete in a 2-minute timed period. The two-mile run timed test was conducted and the amount of time needed to run the distance of two miles was recorded.[2]

Musculoskeletal Assessment

Bilateral isokinetic strength of the knee (flexion/extension) and shoulder (internal/external rotation) was assessed using the Biodex Multi-Joint System 3 Pro (Biodex Medical Systems, Inc, Shirley, NY; see Figure 4). To test isokinetic knee flexion and extension and shoulder internal and external rotation, the subjects were properly fitted to the chair of the device. Padded straps were used to prevent extraneous movements during the test. Isokinetic peak torque for knee flexion and extension strength (concentric/concentric at 60 degrees per second) was measured across five repetitions. For shoulder strength testing, the participant's arm was securely fitted to the dynamometer's arm at 30 degrees of shoulder abduction. Isokinetic peak torque for shoulder internal and external rotation (concentric/concentric at 60 degrees per second) was also measured across five repetitions. Prior to each strength test, the subject performed three practice trials at 50% maximal effort and three practice trials at maximal effort followed by a 60 second rest period. The reliability of isokinetic strength testing had been previously established in the Neuromuscular Research Laboratory with ICC to be 0.73 – 0.97 for the peak torque/body weight.

Data Analysis

All physiological and musculoskeletal laboratory testing, including anaerobic power, anaerobic capacity, maximal oxygen uptake, isokinetic knee strength, and isokinetic shoulder strength are reported as relative to total body weight (kg). Independent t-tests were used to analyze the dependent variable differences between Group 1 (BF $\leq$ 18%) and Group 2 (BF > 18%) ($p < 0.05$).

Results

All results are presented in Table 1. Subjects in Group 1 (≤18% body fat) who met the department of Defense body fat goals performed significantly better than Group 2 (>18% body fat) on seven of the ten tests performed. Group 1 had significantly higher anaerobic capacity scores than Group 2 ($p \leq 0.001$). Maximal oxygen uptake (VO_2 max) scores were significantly higher for Group 1 than Group 2 ($p \leq 0.001$). Out of the three tests of the Army Physical Fitness Test, only push-ups showed significant differences between groups ($p \leq 0.01$), with soldiers in Group 1 having significantly higher scores than Group 2. Group 1 performed significantly better on all measures of isokinetic strength, including shoulder internal and external rotation scores ($p \leq 0.001$), and knee flexion and extension scores ($p \leq 0.001$).

Discussion

As evidenced by data from this study, soldiers achieving the optimal body composition standard of 18% body fat performed significantly better on a majority of physiological and musculoskeletal tests than those who exceeded the standard. On the whole, this research validates the hypothesis that leaner individuals perform better on laboratory physiological and musculoskeletal fitness tests of anaerobic power, aerobic capacity, and isokinetic strength, as well as a component of the APFT. Thus, the Department of Defense should continue to enforce body fat standards in order to enhance the overall fitness of the Army and decrease costs of early discharge and unnecessary musculoskeletal injury.

The results of this study reinforce previous research which has shown that leaner individuals possess greater levels of fitness,[7-10] including a study which found that whole body fat-free mass, specifically muscle mass, contributed to greater strength in a maximal lifting task and greater maximal oxygen uptake.[25] Our study is also in agreement with a 2x2 contingency table analysis in the same study which classified subjects within the standard fat range aerobically fit (VO2Max $\geq$45 ml/kg/min) and subjects above the standard fat range aerobically unfit (VO2Max <45 ml/kg/min).[25] The APFT results in our study conflict with the laboratory test results of physical capacity. Vanderburgh et al[26] has identified that the APFT imposes a significant body mass bias, suggesting that leaner individuals inherently possess the ability to perform better on all parts of the APFT. In a cohort study of Navy Physical Readiness testing from the 2002 cycle, a higher BMI was significantly correlated with decreased Physical Readiness Test scores for both men and women, which included tests of curl-ups, pushups, a 1.5-mile run, a 500-yard run, and a 450-meter swim.[7] Body fat and physical fitness have also been studied in athletic populations. In a study of male judo athletes in Brazil, a higher percent body fat was negatively correlated with performance in activities with body mass locomotion, such as a Cooper running test.[8] Thus, we hypothesized that leaner soldiers would have better scores on the pushup test, sit-up test, and 2-mile timed run. However, it is unknown if participants in the study performed the APFT at maximal effort or if they merely performed each task in order to pass the Army standard requirements. Therefore, this limitation may contribute to the fact that Group 1 did not perform significantly better than Group 2 on the sit-up test and the 2-mile timed run.

Unique from previous studies, which utilized limited tests for physical capacity, our study tested for a wide range of fitness components. Group 1 had better scores in anaerobic capacity, maximal oxygen uptake, push-ups, isokinetic shoulder external and internal rotation, and isokinetic knee extension and flexion. These results suggest that leaner soldiers perform better on tests that encompass a broad array of fitness goals, including anaerobic power, cardiovascular endurance, upper-body push-up endurance, and upper- and lower-body isokinetic strength.

The outcomes of this study present practical applications to the military population. Decreased anaerobic and aerobic capacity may also play a role in injury predisposition in the military population. Since laboratory test results of anaerobic power and aerobic capacity were significantly lower in subjects with higher body fat, these subjects may also have injury risk in the field because they possess a decreased physical capacity to perform tasks which require power and endurance. In a prospective study that looked at injury risk factors in sub-elite rugby players, preseason tests of a vertical jump, 10- and 40-meter sprint, and a multistage aerobic fitness test were measured and later analyzed for subsequent injury occurrence.[27] Researchers found that players with low speed and maximal aerobic capacity, as well as those who had completed less than 18 weeks of training prior to sustaining initial injury, were at increased risk for injury.[27]

Additionally, studies have shown that individuals with higher body fat may possess isokinetic strength deficits, which also may create a greater risk for musculoskeletal injury. A prospective study that utilized isokinetic testing for the hip flexors and extensors as well as the quadriceps and hamstrings in elite sprinters found that out of six subjects who injured their hamstrings within a year of testing, each subject had displayed a weakness in eccentric hamstring contraction and concentric hip extensor contraction on the injured side in comparison to the non-injured side.[28] Another prospective study used isokinetic testing to identify quadriceps-to-hamstrings strength imbalances in professional soccer players.[29] Thirty-five out of 462 athletes eventually sustained hamstring injuries, and a significant number of the injured athletes had untreated muscle strength imbalances from preseason testing.[29] In a study that prospectively looked at isokinetic knee flexion/extension in high school and college athletes, female athletes who later sustained non-contact ACL injury showed a decrease in isokinetic hamstring strength at baseline testing in comparison with matched male controls.[30]

Outside of unnecessary musculoskeletal injury due to increased body fat, studies have found that overweight or obese individuals impose higher health care costs in general.[31-34] A retrospective study comparing healthcare costs of obese and non-obese individuals showed that for each unit BMI increase, healthcare cost increased 2.3%.[32] In a study looking at the relationship between BMI and use of healthcare services, a positive relationship was found between BMI and medical service use, such as medication use and doctor visits.[33] A retrospective cohort study of 1286 individuals found that cost ratios of overweight (BMI > 25

kg/m^2) and obese (BMI >30 kg/m^2) versus normal weight (BMI >20 kg/m^2, <24.9 kg/m^2) were (overweight, obese, respectively) 1.37 and 2.05 for prescription drugs, 0.96 and 1.14 for outpatient services, 1.20 and 1.38 for inpatient care, and 1.10 and 1.36 for all medical care.[34]

Essentially, individuals with excess body fat may possess physiological fitness and musculoskeletal strength deficits, increased risk for injury unnecessary injury, and increased cost of health care. Since this study has begun to identify the link between increased body fat, physiological performance, and injury predisposition, future research is warranted to examine the direct relationship between body composition, health and injury risk, and ultimate physical readiness.

Conclusion

As evidenced by this research, individuals achieving the body fat standard ($\leq$18%) performed significantly better on a majority of physiological and musculoskeletal tests. Since previous research also suggests that excess body fat is linked to a decrease in various fitness components and an increased risk for musculoskeletal injury and other related co-morbidities, the DoD should strive to enforce the maintenance of the optimal body fat standard in order to enhance physical readiness and overall health in military personnel.

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Table 1. Comparison of physiological and musculoskeletal test results between groups

	Group 1 (≤18% BF) Mean ± SD	Group 2 (>18%BF) Mean ± SD
BF%**	13.29 ± 3.71	25.80 ± 5.25
Peak Anaerobic Power (W/kg)	13.07 ± 1.83	12.39 ± 2.07
Mean Anaerobic Capacity (W/kg)**	8.27 ± 0.63	7.24 ± 1.01
VO2 Max (ml/kg/min)**	52.24 ± 5.42	44.12 ± 6.82
Push-ups (2 min^{-1})*	78.17 ± 18.49	65.74 ± 13.88
Sit-ups (2 min^{-1})	73.58 ± 16.16	73.11 ± 14.03
2 Mile Run (min)	15.21 ± 2.29	15.13 ± 1.99
Shoulder Internal Rotation (N/kg)**	66.08 ± 16.27	50.45 ± 14.54
Shoulder External Rotation (N/kg)**	45.39 ± 7.66	36.61 ± 7.43
Knee Flexion (N/kg)**	127.88 ± 23.94	103.62 ± 26.63
Knee Extension (N/kg)**	263.52 ± 48.99	218.98 ± 41.67

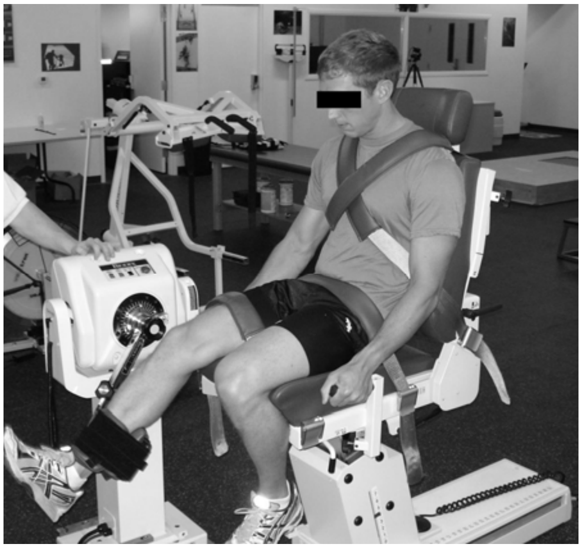
Significant differences between groups: ** $p < 0.001$, *$p < 0.01$

Figure 1.
Body composition analysis using the Bod Pod® Body Composition System (Life Measurement Instruments, Concord, CA)

Figure 2.
Wingate testing on the VeloTron® cycling ergometer (RacerMate, Inc, Seattle WA)

Figure 3.
Maximal VO_2 Testing with the portable metabolic system (Viasys, San Francisco, CA)

Figure 4.
Isokinetic Knee Strength on the Biodex Multi-Joint System 3 Pro (Biodex Medical Systems, Inc, Shirley, NY)



SUPPORTING DATA

Not applicable